

I – Problem Statement Title (EQ 021)

Development of Improved Nonlinear Static Procedure (or Pushover Analysis) for Seismic Design and Evaluation of Bridges

II – Research Problem Statement

Question: How can we improve the current Caltrans procedures to obtain reliable estimates of demand and capacity for seismic design and evaluation of bridges.

According to Seismic Design Criteria (SDC) Version 1.3, February 2004, seismic deformation demands for most bridges are computed by equivalent static analysis or elastic dynamic analysis. Nonlinear response history analysis (RHA) is used to verify designs only for important and/or non-standard bridges. Pushover analysis is implemented on bridge subsystems: column alone, bent alone, or frame that includes multiple columns or bents and the deck.

The preceding procedure should be improved in two ways: First, inelastic behavior should be recognized explicitly in estimating seismic demands. This is essential because, as is well known, equivalent static and elastic dynamic analyses are inappropriate for structures expected to deform significantly into the inelastic range. Second, the dynamics of the bridge should be considered in evaluating structural capacity. Pushover analysis of the complete system—instead of subsystems—would provide a more reliable estimate of structural capacity by considering interaction among various columns and bents.

III – Objective

STAP Roadmap Outcome: 6. Improved Seismic Analysis Tools, Techniques, and Methods

The objective of this research is to develop improved nonlinear static (or pushover) procedures, including those “modes” of vibration that contribute significantly to the seismic demands. Considering the dynamics of the complete structure, this can be achieved by extending the modal pushover analysis (MPA) procedure developed for buildings (Chopra & Goel, 2002 and 2004) to bridges. Without additional conceptual complexity or computational effort, MPA estimates seismic demands for buildings much more accurately than the FEMA-356 procedure (Goel & Chopra, 2004). It should be possible to develop an MPA procedure to estimate seismic demands for bridges that is (1) a major improvement over the current Caltrans procedure, and (2) accurate enough for practical application to seismic design and evaluation of bridges.

The procedure should retain the conceptual and computational simplicity of the pushover procedure currently used by Caltrans, but provide much more accurate results. Additionally, step-by-step implementation of the procedure should be presented and guidelines developed for incorporating the improved procedure in analytical tools, such as W-Frame and SAP2000, currently used by Caltrans.

IV – Background

Current commonly used procedures for seismic analysis of bridges are oversimplified. The structural capacity is determined by pushover analysis of subsystems: columns alone, bent alone, or frame that includes multiple columns or bents and the deck. Seismic demands are determined by equivalent static or elastic dynamic analyses. It is tacitly assumed that this approach is reliable enough for seismic design and evaluation purposes. However, as argued above, this approach should be improved by explicitly considering inelastic behavior of the structure and considering the dynamics of the entire bridge. Although nonlinear RHA may be necessary to estimate seismic demands for non-standard or especially important bridges, it is unreasonable to require this onerous procedure (which entails three-dimensional analysis for several ground motions) for ordinary bridges.

V – Statement of Urgency, Benefits, and Expected Return on Investment

Recent investigations on pushover analysis have raised valid concerns about applicability of currently used pushover analysis for many structures, especially for those where higher mode effects are significant. Therefore, there is an urgent need to establish the range of parameters where currently used pushover analyses can provide accurate estimate of seismic demands of bridge structures. For the range of parameters outside the applicability of current pushover analyses, a simple yet effective pushover analysis is also needed. Since the improved pushover analysis is expected to be conceptually and computationally no more complicated than the current procedures, this procedure would lead to much superior estimates of seismic demands and, hence, achieve seismic safety reliability of bridges.

VI – Related Research

Estimating seismic demands for performance-based earthquake engineering of buildings has been a hot topic for research in recent years. References most closely related to this problem statement are:

1. Chopra, A. K., and Goel, R. K. (2002). "A Modal Pushover Analysis Procedure for Estimating Seismic Demands for Buildings," *Earthquake Engineering and Structural Dynamics*, 31(3):561-582.
2. Chopra, A. K., and Goel, R. K. (2004). "A Modal Pushover Analysis Procedure to Estimate Seismic Demands for Unsymmetric-Plan Buildings," *Earthquake Engineering and Structural Dynamics*, 33(8):903-927.
3. Goel, R. K., and Chopra, A. K. (2004). "Evaluation of Modal and FEMA Pushover Analyses: SAC Buildings," *Earthquake Spectra*, 20(1):225-254.

VII – Deployment Potential

Guidelines for range of parameters for which current pushover analyses provide accurate estimates will be provided. Furthermore, a framework for implementation of the improved procedure in currently used analytical tools such as W-Frame and SAP2000 will be developed.